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Development of Methods Precision Length Measurement Using Transported Laser Interferometer

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Abstract

The paper shows the results of a comparison of a developed transported laser interferometer (TLI) with a measurement interferometer XL-80 Renishaw at the distance 0-60 meters. Testings of a breadboard model of the TLI showed that a difference between the travel measurements of the two interferometers does not exceed 6 μm. The mean value of the difference of indications between the TLI and a Renishaw travel measurer at the distance near 58 m approximately equals to 0,5 μm. Root-mean square deviation of the indications of the interferometers approximately equals to 3 μm. At comparison of the sections with the same name between the TLI and the Renishaw travel measurer, measured at different days, a repeatability of the results for the sections with the same name is noted.

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Keywords: standard of unity of length; transported laser interferometer; measuring basis; comparison

1. Introduction

The breadboard model of a transported laser interferometer (TLI), intended for the solution of an actual problem -

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dissemination of the size of unit of length from the state primary standard of unit of length – metre (GET 2-2010) [1] to a stationary complex of metrological maintenance of gauges of length, the special and secondary standards working in the range up to 60 meters is created. The TLI uses a basis for the corner reflector travel as a part of these standards.

Necessity of maintenance high precision performances of GLONASS in the conditions of growing requirements of consumers and continuous improvement of competing systems GPS, Galileo, COMPAS requires the further development of the GLONASS system and expansions of the standard base of system of maintenance of unity of measuring of lengths [2].

The created TLI should provide the following metrological characteristics: residual systematic error of measuring of travel length on the basis up to 60 m - no more than 10 microns; a mean-square random deviation of the length measurement result in the range up to 60 m - no more than 10 microns.

Presence of such a device as a part of the stationary complex of metrological maintenance of gauges of length in the range up to 60 m will allow one to increase the reliability of dissemination of unit of length in the top echelons of the hierarchical chain.

2. Optical scheme of a transported interferometer

Use a method laser interferometry has found wide application in science and technology [3-5]. The TLI is being constructed according to the Michelson interferometer scheme. The optical scheme of the created interferometer is presented in Fig. 1.

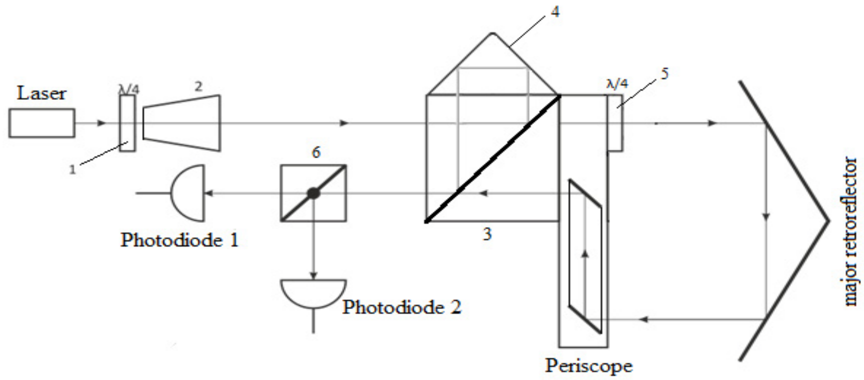


Fig. 1. Optical scheme of a single-wave transported interferometer with the nonpolarizable partitioning of the light beams.

A linearly polarized radiation from a highly stable laser is converted by means of a quarter-wave plate 1 to radiation with circular polarization. Further, the light beam by means of a dilator 2 of a beam is increased in diameter for maintenance of the necessary quantity of a diffraction divergence of the beam. Nonpolarizable beam splitter 3 parts a beam in two beams, each of which have s- and p-polarized components of radiation. One beam is guided to a basic arm of the interferometer and another one is returned in a beam-splitting cube by a "small" retroreflector 4 set in an arm for measuring of travels of the "major" retroreflector. To assure the possibility of the reversive count of interference fringes in a measuring arm of the interferometer the quarter-wave phase plate 5, providing a $\pi/2$ phase shift between the s- and p-polarized components of radiation is erected. The light beam spread in the measuring arm of the interferometer, after reflexion from the translocable corner reflector through a periscope again gets in to a beam-splitting cube 3 to interfere with the light beam spread in a basic arm of the interferometer. After polarization partitioning of the interfering beams by a polarization beam-splitting cube 6 two $\pi/2$-shifted interferograms are registered by the photodiodes 1 and 2. The count of interference fringes taking into account these two signals allows one to consider the true direction of the retroreflector motion and to exclude influence of eventual vibrations from the count of interference fringes. The blanket idea of the reversive account of interference fringes is known at least from the sixties of the last century, see for example [6]. Presently its embodying on the up-to-date element hardware is of interest.

A stabilized single-mode single-frequency solid-state laser «Orvilaz-532-5-S» the radiated frequency of which is tied to the absorption lines of the molecular iodine was used in the interferometer. The relative frequency instability of radiation at averaging 1 s is no more than 10^{-11}. The laser radiates two coaxial beams with wave lengths 532 nm and 1064 nm. Radiant power of each of the beams makes up not less than 5 mW. Use of such a laser will allow one to carry out the two-wave scheme of an interferometer [7, 8] that is an ultimate goal of the work.

For maintenance of necessary parameters of neutralization of the influence of surrounding medium on accuracy of the linear measurements by an interferometric technique, the TLI includes: the meteorological station with 3 temperature sensors (absolute error 0,02 °C), pressure sensor (absolute error 0,05 %), humidity sensor (absolute error 2 %) and CO_2 concentration sensor (absolute error 10 %).

3. TLI testings on the VNIIFTRI measuring basis

For the purpose of the observational working off of the TLI breadboard model acknowledgement of correctness of the chosen technical solutions, an estimate of metrological characteristics of the interferometer, testings of the TLI breadboard model the measuring basis of the VNIIFTRI standard of length were performed.

In structure of a stationary complex of metrological maintenance of the VNIIFTRI length gauges the interferometer Renishaw XL-80 plays an important role of the standard of the keeper of unity of length. The standard keeper Renishaw allows to disseminate the size of the keeped meter to any intervals from 1 micron to 60 m. Accuracy of the linear measurements the executed by the interferometer Renishaw XL-80 makes up ±0,5 ppm [9].

The TLI and Renishaw measuring beams were guided on the corner reflectors of the measuring carriage coaxially and towards each other. The carriage was translocated over 10 sections at the distance about 58 m. After each section the carriage was stopped and indications of standings of a retroreflector and measuring interferometer XL-80 Renishaw were registed. Results of comparison are presented in Table 1.

Table 1. Comparison of the TLI with the interferometer XL-80 Renishaw.

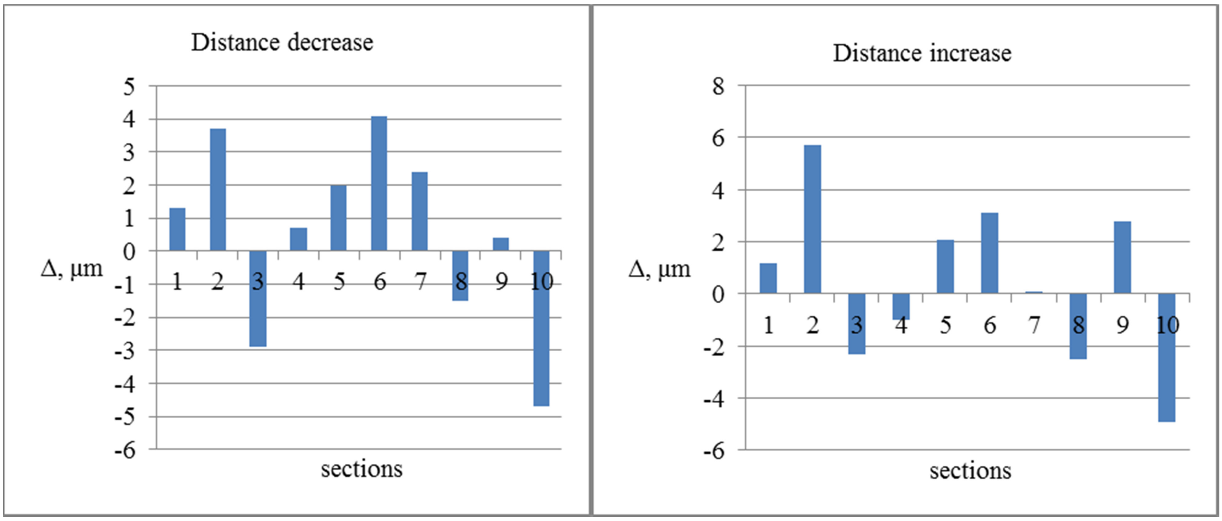
	TLI, μm	Sections, μm	Renishaw, μm	Sections, μm	Δ, μm
	5725284.08		5821146.6		0
	11549548.2	5824264.12	11645414.4	5824267.8	3.68
	17374169.32	5824621.12	17470033.7	5824619.3	-1.82
	23198871.01	5824701.69	23294735.2	5824701.5	-0.19
	29023433.74	5824562.73	29119298.7	5824563.5	0.77
	34848991.81	5825558.07	34944859.5	5825560.8	2.73
	40674134	5825142.19	40770001.5	5825142	-0.19
	46499512.27	5825378.27	46595378	5825376.5	-1.77
	52324713.6	5825201.33	52420581.6	5825203.6	2.27
	58150008.15	5825294.55	58245870.1	5825288.5	-6.05
Without stoppings	58245464		58245465.7		1.7

Root-mean-square deviation of odds of indications of the interferometers equals 2,79 microns that meets the task requirements. At evaluation of standings of a retroreflector in the two devices the data of Renishaw meteorological sensors were used.

At the following stage in each measurer of travels only the data of meteorological parameters of the own meteorological sensors were used. The carriage was translocated at first to one, then in the opposite direction. Effects of checkings are presented in Table 2 and Fig. 2.

Table 2. Comparison of the TLI with the interferometer XL-80 Renishaw measured at the same day at decrease and increase of distances.

Distance decrease					**Distance increase**				
Renishaw, μm	Sections, μm	TLI, μm	Sections, μm	Δ, μm	Renisaw, μm	Sections, μm	TLI, μm	Sections, μm	Δ, μm
5822927.5	5822927.5	5822932.2	5822932.2	-4.7	5821456.2	5821456.2	5821455	5821455	1.2
11646640.7	5823713.2	11646645	5823712.8	0.4	11645768.9	5824312.7	11645762	5824307	5.7
17470373.2	5823732.5	17470379	5823734	-1.5	17470187.6	5824418.7	17470183	5824421	-2.3
23296172.6	5825799.4	23296176	5825797	2.4	23295185.6	5824998	23295182	5824999	-1
29119583.7	5823411.1	29119583	5823407	4.1	29119821.7	5824636.1	29119816	5824634	2.1
34944744.7	5825161	34944742	5825159	2	34945102.8	5825281.1	34945094	5825278	3.1
40770044.4	5825299.7	40770041	5825299	0.7	40770305.9	5825203.1	40770297	5825203	0.1
46594905.5	5824861.1	46594905	5824864	-2.9	46595723.4	5825417.5	46595717	5825420	-2.5
52420621.2	5825715.7	52420617	5825712	3.7	52420963.2	5825239.8	52420954	5825237	2.8
58246517.5	5825896.3	58246512	5825895	1.3	58246261.3	5825298.1	58246257	5825303	-4.9

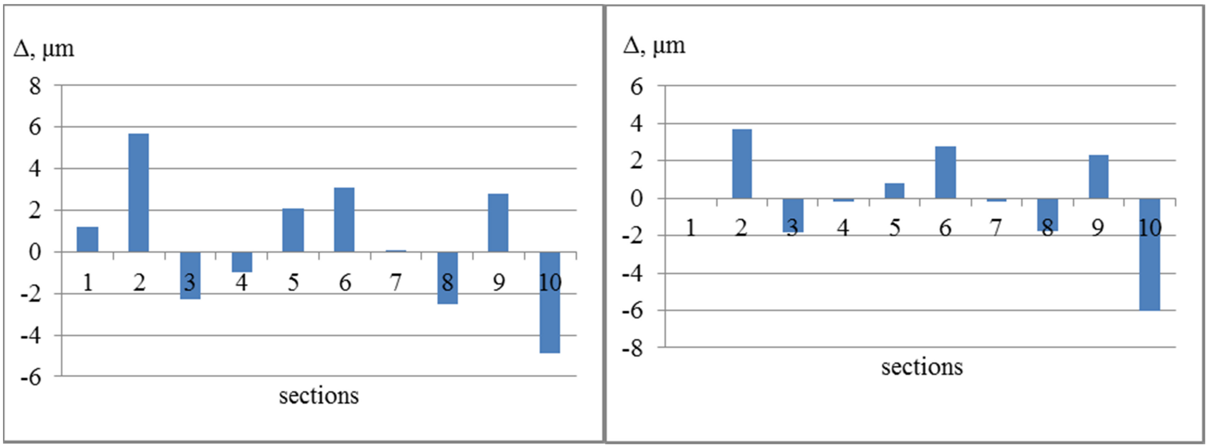


a) b)

Fig. 2. A difference of indications between the TLI and Renishaw, measured at the same day at decrease (a) and increase (b) of distances.

At distance decrease medial arithmetic value of odds of the measured sections of the two interferometers equals 0,55 microns, and a root-mean-square deviation equals 2,74 microns. At distance increase medial arithmetic value of odds of the measured sections of the two interferometers equals 0,43 microns, and a root-mean-square deviation equals 3,04 microns.

At comparison of similar sections of standings of the retroreflector made at different days and with use of the own meteorological parameters for each interferometer, it is possible to note the repeatability of discrepancies of the standings measured by the TLI, and the standings measured by the Renishaw measurer of travels (Fig. 3). This effect, probably, is related to systematic manifestation of local deviations of the real measuring basis from ideally rectilinear.



a) b)

Fig. 3. A difference of indications between the TLI and Renishaw with use of the own meteorological parameters measured at the same day and after a week.

Conclusion

In operation effects of testings of a developed transported laser interferometer on a distance (0-60) meters are featured.

Mean value of odds of indications of the developed TLI and the Renishaw measurer of travels on a distance nearby 58 m approximately equals to 0,5 microns. A root-mean-square deviation of odds of indications of both interferometers approximately equals to 3 microns.

At comparison of lengths of the sections with the same name between the TLI and a Renishaw measurer of travels, measured in different days, repeatability is noted for the sections with the same name. The possible parent of this effect – nonideal straightforwardness of the measuring basis.

References

[1] Alexandrov VS, Zakharenko YuG, Kononova NA, Leibengardt GI, Fedorin VL, Chekirda KV. State primary standard for the unit of length, the meter, GET 2-2010. *Measurement Techniques* 2012; 55: 595-602.
[2] Shchipunov AN, Tatarenkov VM, Denisenko OV, Sil'vestrov IS, Fedotov VN, Vasil'ev MYu, Sokolov DA. A set of standards for support of the uniformity of measurements of length in the range above 24 m: current state and prospects for further development. *Measurement Techniques* 2015; 57: 1228-1232.
[3] Kuznetsov AP, Byalkovskii OA, Gubskii KL, Kozin GI, Protsenko ED, Dodulad EI, Savjolov AS. Measurements of the gas-kinetic pressure in plasma flows emerging from a micropinch discharge by means of laser interferometry. *Plasma Physics Reports* 2014; 40: 290-297.
[4] Maksimenko VV, Kupriyanov LY, Zagaynov VA, Agranovski IE, Khasanov AA. Interference related corrections to classical gas diffusion in a system of small heterogeneities. *The European Physical Journal B - Condensed Matter and Complex Systems* 2013; 86: 186.
[5] Sadovskii SP, Chizhov PA, Bukin VV, Brendel VM, Dolmatov TV, Polivanov YuN, Orlov SN, Garnov SV, Vartapetov SK. Picosecond Laser System with a Wavelength of 193 nm Based on a Solid-State Nd:YAG Laser, Parametric Oscillator, and ArF Amplifier. *Physics of Wave Phenomena* 2014; 22: 223-226
[6] Kiryanov VP, Klistorin IF, Sherbachenko AM. The electronic device of the count and recording for a laser measurer of travels. *Autometering* 1971; 1: 21-35.
[7] Prilepin MT. *Proc. of central research institute of geodesy, cartography and aerial photography* 1957; 114: 127.
[8] Prilepin MT. A geodesy and air photography. *Proc. high schools* 1957; 2.
[9] http://renishaw.ru/ru/xl-system-components--8268